1-1-1991

Modified-atmosphere storage does not substitute for low-temperature storage of strawberry

Khalid N. Al-Redhaiman
Iowa State University

Modified-atmosphere storage does not substitute
for low-temperature storage of strawberry

by

Khalid N. Al-Redhaiman

A Thesis Submitted to the
Graduate Faculty in Partial Fulfillment
of the Requirements for the Degree of
MASTER OF SCIENCE

Major: Horticulture

Approved:

Signatures have been redacted for privacy

Iowa State University
Ames, Iowa
1991

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

'Honeoye' (June-bearing) and 'Tristar' (day-neutral) strawberries were harvested, graded, and then stored for 7 days at 2C or 21C in air (control) or with one of the following eight modified atmospheres: 1.5% O_2, 3.5% O_2, 15% CO_2, 25% CO_2, 1.5% O_2 + 15% CO_2, 1.5% O_2 + 25% CO_2, 3.5% O_2 + 15% CO_2, and 3.5% O_2 + 25% CO_2, all balance N_2. When compared with storage at 21C, storage at 2C reduced weight loss and *Botrytis cinerea* growth in all corresponding sets of storage atmosphere treatments. Increased CO_2 with decreased O_2 controlled weight loss and *B. cinerea* more effectively than treatment with reduced O_2 alone at 21C. Storage at 2C (versus 21C) reduced respiration of both cultivars. Respiration of both cultivars decreased as the O_2 concentration decreased at 21C. 'Tristar' did not produce ethylene at either temperature. 'Honeoye' did not produce ethylene at 2C, but it was produced at 21C. Increased CO_2 and/or decreased O_2 concentrations in the storage atmosphere are not satisfactory substitutes for proper low-temperature storage of strawberries.

INTRODUCTION

Fresh strawberries are perishable and have a maximum shelf life of five to seven days (Hardenburg et al., 1986). They are susceptible to rapid decay due to gray mold rot, which is caused by Botrytis cinerea (Harris and Harvey, 1973; El-Kazzaz et al., 1983). The respiration rate of strawberry is high (169 to 211 mg $CO_2 \cdot kg^{-1} \cdot hr^{-1}$ at 25 to 27C), and suitable postharvest handling methods are required to minimize postharvest losses (Hardenburg et al., 1986). Postharvest losses also can be minimized by forced-air cooling of the fruit to 1C within one hour of harvest (Harvey et al., 1966; Ryall and Pentzer, 1982).

In eastern North America, the majority of strawberries are sold directly to consumers through pick-your-own (PYO) operations. Recently, demand for prepicked strawberries has increased and PYO sales have decreased (Courter and Kitson, 1988). As demand shifts from PYO to prepicked, suitable postharvest handling methods for maintenance of quality must be developed. Refrigeration is both a major capital expenditure, and it is expensive to operate and maintain. It would be ideal if strawberry farmers with small acreages switching from PYO to prepicked could use a means other than refrigeration for storing prepicked strawberries.

Modified atmospheres (MA) and controlled atmospheres (CA) are gaseous environments that have a composition different from that of normal air (78.08% N_2, 20.95% O_2, 0.03% CO_2) (Kader, 1985b). Kidd and West (1922) first reported that storage life was doubled by holding apples in 14% CO_2 and 8% O_2. High concentrations of CO_2 and/or low concentrations of O_2 reduce fruit respiration and inhibit fungal growth, thus extending storage life (Kader, 1985b). However, CO_2 at 30% or greater and/or O_2 at less than 2% caused development of off flavors (Harvey et al., 1966). Wells (1970) was the first researcher to study the effect of MA storage on strawberry shelf life. He compared heat treatments, MA (20% CO_2, 1% O_2),and fungicide treatments, and he found that only high CO_2 and refrigeration (storage at 1.7C) reduced total loss.

CA storage with increased CO_2 and/or reduced O_2 has been used successfully to extend postharvest longevity of strawberries. Elevated concentrations of CO_2 inhibit decay and retard softening without impairing the delicate flavor of the berries. Furthermore, the effects of elevated CO_2 persisted after removal to air. Thus, compared with air at the same temperature, increased concentrations of CO_2 extended strawberry storage life by more than 50% (Harris and Harvey, 1973). Lipton (1975) reported that CA storage delayed fruit ripening, and Woodward and Topping (1972), Siriphanich (1980), and Li and Kader (1989) indicated that CA reduced the respiration and ethylene production rates of strawberries. El-Kazzaz et al. (1983) and Li and Kader (1989) also reported that CA retarded softening.

The purpose of this research was to determine whether or not modified-atmosphere storage could be used satisfactorily as a substitute for low-temperature storage of strawberries. The specific objective of this research was to determine the effect of combinations of low O_2 and/or high CO_2 concentrations on weight loss, percentage mold growth, respiration, and ethylene production of strawberries stored at two temperatures.

LITERATURE REVIEW

Characteristics and Postharvest Handling of Strawberry

The strawberry fruit is 85 to 90% water, about 8.4% structural carbohydrates, 4 to 6% sugars, and 0.5 to 1.8% titratable acidity, with citric acid as the main organic acid (Watt and Merrill, 1975). The epidermis and cuticle of the strawberry is thin and soft. It is injured easily and subsequently can be attacked by decay organisms such as _Botrytis_ _cinerea_ and _Rhizopus_ _spp_. (Ryall and Pentzer, 1974; Mitchell, 1985).

At 0C, the strawberry respires rapidly with a vital heat output of 680.4 to 982.8 $kcal \cdot ton^{-1} \cdot day^{-1}$ (Pantastico, 1975). This elevated respiratory rate causes the strawberry to deteriorate quickly, and it limits storage life to about one week. Strawberry is a nonclimacteric fruit, and therefore, a burst of CO_2 or C_2H_4 production is not observed during ripening or storage (Haller et al., 1932). In most cases, strawberry respiration increases slightly with time in storage (Haller et al., 1932).

Several researchers have reported that strawberries produce trace amounts of C_2H_4 (0.01 to 0.1 $\mu l \cdot kg^{-1} \cdot hr^{-1}$ at 20C), that exogenous C_2H_4 has no effect on ripening, and that C_2H_4 removal during postharvest handling offers no advantages

(Kader, 1980; Gerheart, 1930; Rhodes, 1970; Siriphanich, 1980). Fresh-market strawberries have a limited postharvest life at ambient temperatures, and this reduced shelf life often is caused by fungal invasion (Dennis and Mountford, 1975).

Importance of temperature

Temperature management is the most important method of maintaining the postharvest quality of fruits. Sommer (1985) reported that temperature control is considered central to all modern postharvest handling systems because low temperatures maximize postharvest life and decrease fungal growth.

Kader (1985b) and Lipton (1975) reported that a specific concentration of CO_2 or O_2 in the storage atmosphere may be beneficial at a specific temperature, but it can be clearly harmful at another. Mitchell et al. (1964) reported that as temperature rises, the useful life of strawberries decreases rapidly because of decay. At 0, 5, and 21C, strawberries remained in marketable condition for about 7-10, 3-5, and 1-2 days, respectively (Mitchell et al., 1964).

Matsumoto and Sommer (1967) reported that germination spores and young mycelia of some Rhizopus spp. are controlled properly when fruit is stored at approximately 5C because they are sensitive to low temperature. On the other hand, Eckert and Sommer (1967) reported that Botrytis cinerea is able to continue growth at 0C.

Importance of precooling

When the temperature of fruit is lowered immediately after harvest, storage life is maximized. Most small fruits, including the strawberry, can be cooled to close to 0C without danger of chilling injury (Spayd et al., 1990). Sommer et al. (1973) reported that cooling strawberries to 1.5 to 2.0C by forced-air cooling immediately after harvest removed field heat, maintained fruit quality, and extended postharvest life.

Modified Atmospheres for Transit and Holding

Terminology

A modified atmosphere is a system for produce storage in which the gas composition differs substantially from air. The proportions of nitrogen (N_2), oxygen (O_2), or carbon dioxide (CO_2) in air may be changed, and other gases such as carbon monoxide or ethylene may be added to the system (Kader, 1985b; Ryall and Lipton, 1972). A gas mixture is termed a controlled atmosphere (CA) if it is adjusted periodically or constantly to compensate for changes caused by fruit metabolism (El-Kazzaz et al., 1983). Lipton (1975), Ryall and Lipton (1972), and Kader (1985b) reported that MA is in principle the same as CA, but the difference betweenn them is one of degree and method of control. Lipton (1975) reported that CO_2 derived from either dry ice or fruit respiration is allowed to accumulate and O_2 is allowed to decrease in MA.

Overview

Postharvest handling of fruits and vegetables includes the following treatments: refrigeration, chemical (fungicide), heat, hypobaric, radiation, and modified-atmosphere storage, or a combination of them. CA or MA may increase the benefits derived from refrigeration (Metilitskii et al., 1983). CA generally refers to a decrease in O_2 and increase in CO_2 and/or N_2, while MA is similar in principle but without adjustment of the gases to a specific concentration (Maas, 1981). Harris and Harvey (1973) reported that the best concentration of CO_2, one that eliminates decay without injuring the fruit, depends upon temperature of the fruit, time of exposure to CO_2, and possibly other factors such as variety and maturity of the fruit.

Lipton (1975) reported that strawberries are considered the best-suited fruit for CA storage. Ryall and Lipton (1979) and Kader (1985b) reported that strawberries are stored in MA more often during transit than under other conditions. These investigators also reported that fruits stored in CA maintained quality at a specific air temperature, which can be obtained only through refrigeration. Tissue injury and off-flavor development may be harmful side effects of MA storage (Shaw, 1969; Ryall and Pentzer, 1974; Woodward and Topping, 1972).

El-Kazzaz et al. (1983), Shaw (1969), Couey et al. (1966), and Woodward and Topping (1972) reported the effects of CA on postharvest physiology and quality attributes of strawberry. Kader (1985b) reported that an increased concentration of CO_2 (10 to 15%) significantly inhibited development of _B. cinerea_ rot on strawberries, cherries, and other fruit. CA lowered respiration and ethylene production (Woodward and Topping, 1972; Siriphanich, 1980; Li and Kader, 1989). Herner (1987) reported that because CO_2 is a product of respiration, the respiration rate will decrease as the concentration of CO_2 in the atmosphere increases.

Burg and Burg (1967) showed that CO_2 inhibits the mode of action of C_2H_4. They also showed that CO_2 inhibits the activity of respiratory enzymes such as succinate dehydrogenase. El-Kazzaz et al. (1983), Li and Kader (1989), Harris and Harvey (1973), and Ryall and Pentzer (1974) reported that CA retarded the softening of strawberries. Ryall and Pentzer (1974) found that when fruits were stored at high CO_2 concentrations, fruit firmness persisted.

Low O_2

Couey and Wells (1970) reported that in commercial applications, the use of low-oxygen atmospheres to control ripening and decay of fresh commodities during transport and storage has become limited. Development of off-flavors can occur at O_2 concentrations as low as 1% (Couey et al., 1966). Only low concentrations of oxygen, 0.5% or less, reduced the decay of fresh strawberries caused by *B. cinerea* (Couey et al., 1966) The differences in response to low-oxygen atmospheres among different strawberry cultivars were slight (Couey et al., 1966). Previous investigations have shown that strawberries developed off-flavors at low oxygen concentrations (approximately 1%) that significantly reduced decay during storage life (Sommer, 1985; Li and Kader, 1989; Couey and Wells, 1970; Couey et al., 1966). Thus, the narrow effective range of O_2 concentrations that do not cause off-flavors may lead to reduced use of low-O_2 atmosphere storage for strawberry.

High CO_2

The carbon dioxide concentration during storage and shipment of fruit is important. Atmospheres enriched with CO_2 have been used for many years to reduce postharvest decay of strawberry (Brooks et al., 1932, Couey and Wells, 1970; Browne et al., 1984; Harvey, 1982; Ryall and Penzer, 1974; Winter et al., 1936).

Browne et al. (1984) showed that CO_2 at 3, 5, or 10% in air did not consistently retard the decay caused by B. cinerea during six days at 2C or during subsequent shelf life in air at 15C. These CO_2 concentrations also did not reduce wastage or extend the postharvest life of 'Cambridge Favorite' strawberry. On the other hand, Woodward and Topping (1972) found that strawberries remained in good condition for 10 days after storage at 3C in air with 5, 10, 15, and 20% CO_2 and that all CO_2 concentrations reduced decay due to B. cinerea. El-Kazzaz et al. (1983) reported that off-flavors were detected after treatment with air with 15% CO_2. Smith (1957), Li and Kader (1989), Woodward and Topping (1972), and Harris and Harvey (1973) reported that greater concentrations of CO_2, approximately 20%, retarded fungal decay in fruit during transport. Harris and Harvey (1973) reported that increased concentrations of CO_2, 20 and 30%, have controlled more decay in California strawberries than have lower concentrations (0 and 10%).

Wells and Uota (1970) reported that CO_2 concentrations greater than 10% inhibited growth of Rhizopus spp. rot and that CO_2 concentrations greater than 20% inhibited B. cinerea.

Combined Low O_2-High CO_2

The resultant effect of some combination of high-CO_2 and low-O_2 atmospheres is synergistic (Li and Kader., 1989). Sommer (1985) reported that the commonly used storage atmospheres of 2 to 4% O_2 and 5 to 7% CO_2 suppress respiration and delay ripening of fruit, but such results cannot be achieved with either O_2 or CO_2 controlled atmospheres alone. The concentration of O_2 alone needs to decrease to 1% or less, and the concentration of CO_2 needs to be increased to 15% or more to achieve effects similar to those of the combined low O_2 and high CO_2 atmosphere (Sommer, 1985). Kader (1985b) reported that the best CA combination may depend upon cultivar, length of storage, and temperature. Li and Kader (1989) found that the residual effects on strawberries were more pronounced when they were stored under the combination of reduced O_2 and elevated CO_2 than under only lowered O_2 or elevated CO_2.

MATERIALS AND METHODS

June-bearing 'Honeoye' and day-neutral 'Tristar' strawberries (Fragaria ×ananassa Duch.) were used for this research. 'Honeoye' strawberries were obtained from a local commercial grower, and 'Tristar' strawberries were produced at the Iowa State University Horticulture Station. Fruit were harvested at the red-ripe stage and transported to the laboratory within 30 min. One-half of the 'Honeoye' strawberries were cooled to 5C immediately by using forced-air cooling for 30 to 45 min. Berries then were sorted by color and size. Sample weight was approximately 300g per replicate, distributed into two plastic mesh baskets in each MA chamber.

Fruit were exposed to an air control and eight modified atmospheres (MA): 1.5% O_2, 3.5% O_2, 15% CO_2, 25% CO_2, 1.5% O_2 + 15% CO_2, 1.5% O_2 + 25% CO_2, 3.5% O_2 + 15% CO_2, and 3.5% O_2 + 25% CO_2, balance N_2. Eighteen, 9.8-liter desiccators were placed in a cooler at 2 ± 0.5C, and another eighteen desiccators were placed in the laboratory at 21 ± 2C. Mixtures of the desired test atmosphere were obtained by the procedure of Morris (1969). Test atmospheres were passed through the desiccators at one air exchange per hour by using capillary tubes for flow control.

Samples of the test atmospheres were collected at inlets (every 24 hr) and outlets (every 12 hr) of the desiccators and analyzed by using a Varian model 3700 gas chromatograph as described previously (Sinska and Gladon, 1984). The test atmospheres were humidified (85 to 90% relative humidity) as described previously (Diesburg et al., 1989). After seven days in the test atmosphere, final fresh weight and percentage B. cinerea incidence were measured. Production rates for CO_2 and C_2H_4 were calculated by the formula : (Δ O_2%, CO_2% or μl C_2H_4/l / 100) $\times$ (flow rate (ml/hr)) /(sample weight(kg)) (Kader, 1985a).

The experimental design with 'Honeoye' was three replications over time of a 2×2×9 factorial. The factors were two cooling treatments (cooled versus uncooled), two storage temperatures (2 and 21C), and nine MA treatments, respectively. Four replications over time of a 2×9 factorial were used with 'Tristar', with two storage temperatures (2 and 21C) and nine MA treatments, respectively. Analysis of variance was performed (general linear model, PROC GLM) to test the effects of the various treatments (SAS Institute, 1985). When F values were significant, means were compared by LSD at the 5% level.

RESULTS

Weight loss, mold growth, respiration, and ethylene production did not differ among cooled and noncooled 'Honeoye' strawberries at either temperature (data presented in Appendix A). Therefore, data from 'Honeoye' were pooled and subsequent experiments with 'Tristar' did not include forced-air cooling treatments.

Weight Loss

Low temperature (2C) reduced weight loss of 'Honeoye' and 'Tristar' strawberries when compared with storage at 21C (Table 1). There were differences in weight loss of 'Honeoye' strawberry among modified the MA treatments at both temperatures (Table 1). Least weight loss occurred with 15 and 25% CO_2, and the greatest loss occurred at 1.5% O_2, 3.5% O_2, 1.5% O_2 + 15% CO_2, 3.5% O_2 + 15% CO_2 or air (Table 1). After 'Tristar' strawberries were stored for seven days, there were differences in weight loss among MA treatments at both temperatures (Table 1). At 2C, there was more weight loss at 1.5% O_2 and 15% CO_2 than there was in air (Table 1). A high CO_2 (15 and 25%) atmosphere resulted in the least weight loss at 21C (Table 1). At 21C, berries under the combination treatments of 1.5% O_2 + 25% CO_2 or 3.5% O_2 + 25% CO_2 lost an intermediate amount of weight (Table 1). The combined O_2 and lower CO_2 concentrations (1.5% O_2 + 15% CO_2 and 3.5% O_2 + 15% CO_2) were the same as the 1.5% O_2, 3.5% O_2, and air treatments.

Fungal Growth

Fungal growth caused by B. cinerea was the only form observed. No fungal growth was observed in either 'Honeoye' or 'Tristar' strawberries at 2C (data not presented). Fungal growth was not observed under high CO_2 treatments (15 or 25% CO_2) in either 'Honeoye' or 'Tristar' strawberries at 21C (Fig. 1 and Fig. 2). 'Honeoye' berries held in air had the greatest percentage mold growth. Berries held in 1.5% O_2 + 0% CO_2, 3.5% O_2 + 0% CO_2, 1.5% O_2 + 15% CO_2, and 3.5% O_2 + 15% CO_2 had less percentage mold growth than those held in air, but they had more percentage mold growth than berries held in 1.5% O_2 + 25% CO_2 and 3.5% O_2 + 25% CO_2 (Fig. 1). For 'Tristar', berries held in air, 1.5% O_2 + 0% CO_2, 3.5% O_2 + 0% CO_2, 1.5% O_2 + 15% CO_2, and 3.5% O_2 + 15% CO_2 had the greatest percentage mold growth. Berries held in 3.5% O_2 + 25% CO_2 had less percentage mold growth than the previous group of five MA treatments, and 1.5% O_2 + 25% CO_2 had less percentage mold growth than 3.5% O_2 + 25% CO_2 (Fig. 2).

Respiration

There were no differences among modified atmosphere treatments of either 'Honeoye' or 'Tristar' for respiration at 2C for any day (Table B1 and Table B2). For both cultivars stored at 21C, the only apparent trend was a general increase in the respiratory rate as the time in storage increased (Table 2 and Table 3). For both cultivars, the lowest rate of respiration was obtained in the MA treatments that contained 0% O_2, but differences among MA treatments were not observed consistently.

Ethylene Production

Ethylene production was not detected in 'Tristar' strawberries during seven days of storage at either 2C or 21C (data not presented). Ethylene was not produced in 'Honeoye' strawberries stored at 2C (Table A1), but ethylene was detected in 'Honeoye' stored at 21C (Table 4). Ethylene production was inhibited completely by a lack of O_2 during seven days of storage (Table 4). In several cases, ethylene production rates of berries held in air was greater than the ethylene production rates of berries held in one of the MA treatments.

Table 1. Influence of modified atmosphere storage treatments on weight loss of 'Honeoye' and 'Tristar'strawberries after seven days of storage at different temperatures

Treatment		Weight Loss(%)			
		'Honeoye'[Z]		'Tristar'[Y]	
O_2 (%)	CO_2 (%)	2C	21C	2C	21C
1.5	0.0	3.7	28.9	3.8	49.2
3.5	0.0	2.4	32.4	2.4	51.9
0.0	15.0	3.8	6.5	4.0	2.9
0.0	25.0	2.1	5.5	2.1	2.8
1.5	15.0	3.6	24.7	2.5	47.7
1.5	25.0	2.6	17.1	2.1	26.5
3.5	15.0	1.9	29.6	1.7	53.5
3.5	25.0	2.2	19.6	1.8	38.7
Control (Air)		2.1	29.9	2.1	51.4
MA LSD (.05)		1.5	10.1	0.5	8.6
$P>F_{temp}$		0.0001		0.0001	

[Z] Data were pooled values of cooled and noncooled treatments for 'Honeoye' and each value is the mean of three replications

[Y] Each value is the mean of four replications for 'Tristar'

Table 2. Influence of modified atmosphere treatments on respiration rate of 'Honeoye' strawberry during seven days of storage at 21C[z]

Treatment		Respiration Rate (ml $CO_2 \cdot kg^{-1} \cdot hr^{-1}$)					
		Days in Storage					
O_2 (%)	CO_2 (%)	2	3	4	5	6	7
1.5	0.0	25.2	23.1	35.2	39.95	45.15	44.2
3.5	0.0	29.95	34.7	51.35	52.3	48.95	51.8
0.0	15.0	18.85	11.5	18.35	18.85	14.75	15.51
0.0	25.0	7.9	5.4	7.9	11.5	10.95	14.55
1.5	15.0	16.95	15.6	29.75	38.0	42.3	36.6
1.5	25.0	20.7	24.7	28.3	26.65	17.6	26.65
3.5	15.0	18.1	25.2	36.6	38.35	34.7	41.65
3.5	25.0	20.0	15.5	24.5	27.55	27.35	26.9
Air Control		33.75	26.6	44.2	54.15	71.3	50.35
$LSD_{0.05}$		ns[y]	11.67	18.73	13.9	13.87	19.01

[z] Data were pooled values of cooled and noncooled treatments, and each value is the mean of three replications

[y] ns= no significant difference

Table 3. Influence of modified atmosphere treatments on respiration rate of 'Tristar' strawberry during seven days of storage at 21C[z]

Treatment		Respiration Rate (ml $CO_2 \cdot kg^{-1} \cdot hr^{-1}$)					
		Days in Storage					
O_2 (%)	CO_2 (%)	2	3	4	5	6	7
1.5	0.0	15.2	27.6	49.4	61.8	46.6	31.4
3.5	0.0	23.8	32.2	60.8	46.6	38.0	39.9
0.0	15.0	10.5	9.0	5.9	7.3	11.4	9.2
0.0	25.0	8.3	3.5	8.1	11.4	9.5	15.2
1.5	15.0	31.4	18.1	24.7	33.3	36.1	40.9
1.5	25.0	17.1	24.7	17.1	23.8	33.3	32.3
3.5	15.0	12.4	20.0	20.9	47.5	38.0	31.4
3.5	25.0	9.0	16.2	9.5	10.5	31.4	23.8
Air Control		19.0	48.5	57.0	52.3	58.0	58.0
$LSD_{0.05}$		14.01	ns[y]	16.4	23.35	19.69	ns

[z] Each value is the mean of four replications
[y] ns= no significant difference

Table 4. Influence of modified atmosphere treatments on ethylene production of 'Honeoye' strawberry during seven days of storage at 21C[z]

Treatment		Ethylene Production ($\mu l\ C_2H_4 \cdot kg^{-1} \cdot hr^{-1}$)					
		Days in Storage					
O_2 (%)	CO_2 (%)	2	3	4	5	6	7
1.5	0.0	0.0	0.0	0.005	0.015	0.0	0.093
3.5	0.0	0.04	0.154	0.135	0.130	0.0	0.0
0.0	15.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	25.0	0.0	0.0	0.0	0.0	0.0	0.0
1.5	15.0	0.0	0.025	0.115	0.005	0.005	0.015
1.5	25.0	0.0	0.0	0.0	0.0	0.0018	0.0
3.5	15.0	0.009	0.108	0.245	0.170	0.044	0.03
3.5	25.0	0.0	0.0	0.012	0.089	0.018	0.0075
Air Control		0.365	0.510	0.330	0.195	0.145	0.112
$LSD_{0.05}$		0.10	0.163	0.185	ns[y]	ns	ns

[z]Data were pooled values of cooled and noncooled treatments, and each value is the mean of three replications
[y]ns= no significant difference

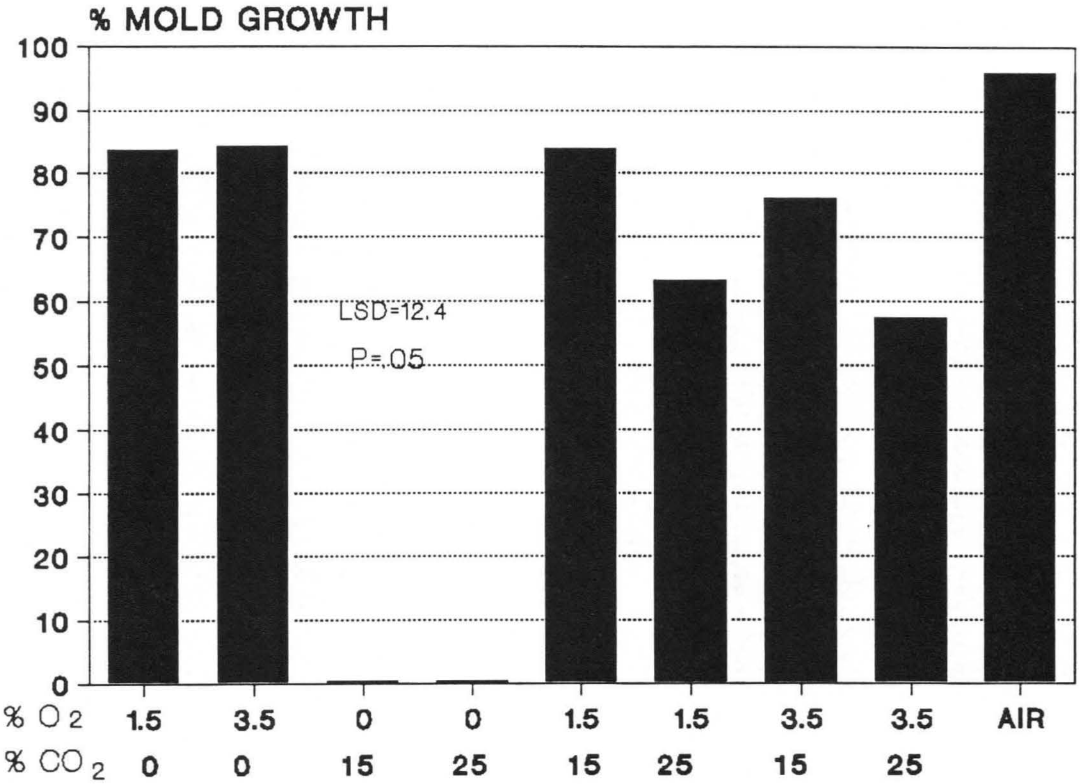

Figure 1. Influence of modified atmosphere on percentage mold growth of 'Honeoye' strawberry after seven days of storage at 21C

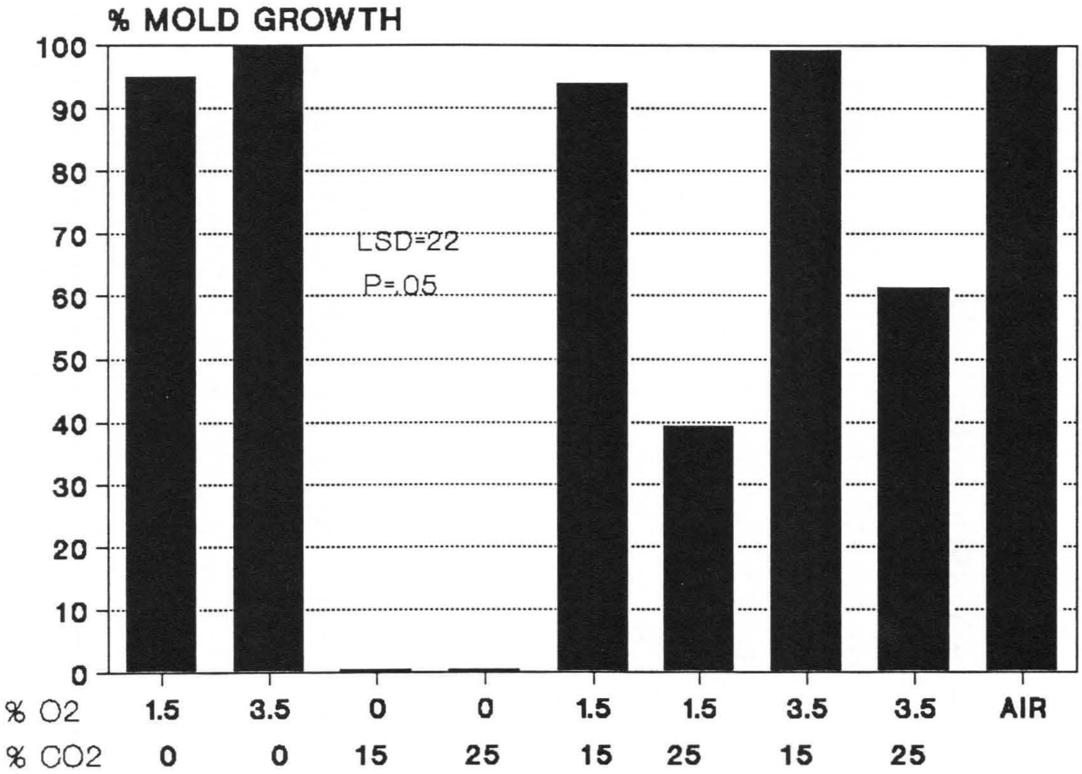

Figure 2. Influence of modified atmosphere on percentage mold growth of 'Tristar' strawberry after seven days of storage at 21C

DISCUSSION

In the 1990 trials, there were no differences in weight loss, mold growth, respiration rate, or ethylene production between cooled and noncooled 'Honeoye' strawberries stored 2C or 21C. These results may have been due to environmental conditions, such as fruit temperature at harvest. However, a more plausible explanation is that the fruits were cooled then graded (at room temperature) and this return to room temperature for grading probably nullified the effects of the cooling treatment.

There was no B. cinerea observed at 2C in any of the MA treatments for either 'Honeoye' or 'Tristar' strawberries during the seven days of storage. Furthermore at 21C, B. cinerea growth was inhibited completely at 0% O_2 + 15% CO_2 or 0% O_2 + 25% CO_2 and it was reduced under the several of modified atmosphere treatments compared with fruits held in air.

During seven days of storage, the most important factor to maintain good quality of 'Honeoye' and 'Tristar' strawberries was low temperature (2C), the modified atmosphere treatments could not overcome the detrimental effects of a higher temperature (21C). Lipton (1975) reported the useful life of strawberries decreased rapidly as the temperature increased, mainly as a result of decay due to fungal growth. In our study, 'Honeoye' and 'Tristar' strawberries were in good condition after seven days of storage at low temperature (2C).

Weight Loss

For all MA treatments, weight loss was lower at 2C compared with 21C (except for 15% CO_2 and 25% CO_2 at 21C). Differences in the rate of respiration for 'Honeoye' and 'Tristar' strawberries in the various MA treatments supported this finding. Mohamed et al. (1986) reported that temperature and storage duration have marked effects on both physical and chemical properties of fruits during cold storage. They reported that 'Tioga' strawberries can be stored for 14 days and 6 days at 0 and 5C, respectively, without marked deterioration. In agreement with our results, Harvey (1967) reported that if berry temperature is maintained below 4.4C, no measurable benefit is realized from a high CO_2 atmosphere.

Fungal Growth

Harvey (1967) reported that high CO_2 was a particularly effective MA treatment when berry storage temperatures are greater than 4.4C, but is not so when temperatures are less than 4.4C. He also reported that maintaining the concentration of CO_2 at 13 to 27% in sealed pallets substantially reduced mold growth. El-Kazzaz et al. (1983) stated that 15% CO_2 in air was the most effective MA in terms of reducing fruit decay. Harris and Harvey (1973) determined that CO_2 concentrations of 20 and 30% were more effective in controlling decay than were 0 and 10%. Sommer et al. (1973) found that high CO_2 effectively suppressed mold growth when temperatures were above 5C, but at lower temperatures, the effectiveness was modest or undetectable because little fungal growth occurred, without regard to the MA treatment. Smith (1957) and Li and Kader (1989) reported that a high concentration of CO_2 (20%) decreased fungal decay of fruit during storage.

In this research, B. cinerea growth commenced on the second day of storage at 3.5% O_2 at 21C. It spread to other fruits quickly as a result of the high temperature and high humidity in the MA chambers. In addition , B. cinerea growth was not detected in either 'Honeoye' or 'Tristar' strawberries at 2C or 21C when the berries were held in an atmosphere that contained no O_2. In agreement with our results, Follustad (1966) reported that at concentrations of O_2 less than 1%, the growth of decay fungi was reduced. Couey et al. (1966) determined that decay caused by B. cinerea was reduced at concentrations of 1.5% O_2 or less.

CO_2 concentrations of 15 and 25% at 0% O_2 completely inhibited growth of B. cinerea at 21C and the combination of lowered O_2 and elevated CO_2 MA treatments (1.5% O_2 + 25% CO_2, 3.5% O_2 + 25 % CO_2) reduced B. cinerea growth when compared with air, but the flavor of such strawberries was unacceptable (data not presented).

Respiration

Temperature was the most important factor in the reduction of the respiration rate of 'Honeoye' and 'Tristar' strawberries. The respiration rates of 'Honeoye' and 'Tristar' strawberries were lower at 2C than at 21C for all MA treatments (except for 15% CO_2 and 25% CO_2 at 21C).

The respiration rate of 'Honeoye' strawberries on the second day was six times greater at 21C than at 2C. Maxie et al. (1959) determined that the rate of respiration of fresh 'Shasta' strawberries soon after harvest was about 7.2 times greater at 20C than at 0C.

Lipton (1975) reported that CA or MA may be beneficial at one temperature but decidedly harmful at another. Li and Kader (1989) found that CA reduced the respiration rate of strawberries. Kubo et al.(1990) found that high CO_2 atmospheres decreased respiration in climacteric fruit which produced ethylene, although high CO_2 had little or no effect on respiration of nonclimacteric fruit (e.g., strawberry).

Ethylene Production

There was no C_2H_4 production detected in 'Honeoye' strawberries stored at 2C in any MA treatment. In agreement with these findings, Lougheed (1987) reported that within the normal range of storage temperatures, the effects of ethylene are directly controlled by temperature. Wills et al. (1981)

reported that the propensity to produce ethylene also may be weakened by storage at low temperature.

The production of ethylene by 'Honeoye' strawberries was inhibited during seven days of storage at 21C under high CO_2 concentrations (15% and 25%) when there was no O_2. Likewise, reduced O_2 concentrations and MA treatments that combined low O_2 with elevated CO_2 reduced C_2H_4 production partially. Burg and Burg (1967) reported that CO_2 inhibited C_2H_4 action competitively and helped regulate C_2H_4 biosynthesis. El-Kazzaz et al. (1983) found that there was no ethylene production by 'Aika' strawberries during 8 days of storage at 15% CO_2 in air at 0.6 ± 0.5C. Lougheed (1987), Wills et al. (1981), and Li and Kader (1989) all reported that by either increasing the CO_2 concentration or decreasing the O_2 concentration, they were able to reduce C_2H_4 production.

SUMMARY AND CONCLUSIONS

Cooled and noncooled 'Honeoye' strawberries were similar in terms of mold growth at 2C and at 21C. High CO_2 atmospheres (15% CO_2 and 25% CO_2) inhibited B. cinerea growth at 21C. There was no difference between 3.5% O_2 and normal air in terms of the reduction of mold growth at 21C.

In all modified atmospheres except 15% CO_2 and 25% CO_2, weight loss of 'Honeoye' and 'Tristar' was less at 2C than at 21C.

Growth of B. cinerea could be inhibited during seven days of storage of 'Honeoye' or 'Tristar' strawberries by low temperature (2C).

The combination of low O_2 and high CO_2 (1.5% O_2 + 25% CO_2 and 3.5% O_2 + 25% CO_2) reduced growth of B. cinerea better than did low O_2 (1.5% O_2 and 3.5% O_2) alone at 21C. According to our visual observations, there was no difference in terms of mold growth between 3.5% O_2 + 0% CO_2 or air (control) at 21C.

The respiration rates of 'Honeoye' and 'Tristar' were similar in air (control) and in all MA at 2C. Elevated carbon dioxide (15% CO_2 and 25% CO_2) was the most effective modified atmosphere in reducing respiration rate of 'Honeoye' and 'Tristar' strawberries when they were stored for seven days at 21C, and this effect was caused by a complete lack of O_2.

No ethylene was detected in 'Tristar' at either 2C or 21C. Also, there was no ethylene detected in 'Honeoye' at 2C. At 21C, only 0% O_2 + 15% CO_2 and 0% O_2 + 25% CO_2 inhibited ethylene production by 'Honeoye' during the seven days of storage, whereas low O_2 and its combinations with high CO_2 reduced ethylene production when compared with air.

Finally, properly controlled temperature (2C) is important both in maintaining strawberry quality and in increasing its useful life. High CO_2 and low O_2 modified atmospheres and their combination are not adequate substitutes for low temperature storage (2C). Further investigation is needed to study the influence of low O_2 and high CO_2 on off-flavor development.

LITERATURE CITED

Brooks, C., E. V. Miller, C. O. Brotaly, J. S. Cooley, P. V. Mook, and H. B. Jannson. 1932. Effect of solid and gaseous carbon dioxide upon transit diseases of certain fruits and vegetables. U. S. Dep. Agric. Tech. Bull. No. 318. 60pp.

Browne, K. M., J. D. Geeson, and C. Dennis. 1984. The effect of harvest date and CO_2-enriched storage atmospheres on storage and shelf-life of strawberries. J. Hortic. Sci. 59:197-204.

Burg, S. P. and E. A. Burg. 1967. Molecular requirements for the biological activity of ethylene. Plant Physiol. 42: 144-152.

Couey, H. M. and J. M. Wells. 1970. Low oxygen or high-CO_2 atmospheres to control postharvest decay of strawberries. Phytopathology 60:47-49.

Couey, H. M., M. N. Follstad, and M. Uota. 1966. Low oxygen atmospheres for control of postharvest decay of fresh strawberries. Phytopathology 56:1339-1341.

Courter, J. W. and M. Kitson. 1988. 1987 Survey of pick-your-own strawberry consumers. Advances in Strawberry Production 7:39-41.

Dennis, C. and J. Mountford. 1975. The fungal flora of soft fruits in relation to storage and spoilage. Ann. Appl. Biol. 79:141-147.

Diesburg, K. L., N. E. Christians, R. J. Gladon. 1989. A continuous air-exchange roomette and gas-meting system. CropScience. 29:344-348.

Eckert, J. W. and N. F. Sommer. 1967. Control of diseases of fruits and vegetables by postharvest treatments. Annu. Rev. Phytopathol. 5:391-432.

El-Kazzaz, M. K., N. F. Sommer, and R. J. Fortlage. 1983. Effect of different atmospheres on postharvest decay and quality of fresh strawberries. Phytopathology 73:282-285.

Follstad, M. N. 1966. Mycelial growth rate and sporulation of Alternaria tenuis, Botrytis cinerea, Cladosporium herbarium, and Rhizopus stolonifer in low oxygen atmospheres. Phytopathology 56:1098-1099.

Gerheart, A. R. 1930. Respiration in strawberry fruits. Bot. Gaz. 89:40-66.

Haller, M. H., P. L. Harding, and D. H. Rose. 1932. Studies on the respiration of strawberry and raspberry fruits. Circular No. 613. U. S. Dep. Agric., Washington DC. 13 pp.

Hardenburg, R. E., A. E. Watada, and C. Y. Wang. 1986. The commercial storage of fruits, vegetables, and florist and nursery stocks. Agricultural Handbook No. 66. U. S. Dep. Agric., A. R. S., Beltsville, MD. 130 pp.

Harris, C. M. and J. M. Harvey. 1973. Quality and decay of California strawberries stored in CO_2-enriched atmospheres. Plant Dis. Rptr. 57:44-46.

Harvey, J. M. 1967. Modified atmospheres in transport. United Fresh Fruit and Vegetables Association Yearbook. pp. 193-194. United Fresh Fruit and Vegetables Assn., Washington, D. C.

Harvey, J. M. 1982. CO_2 atmospheres for truck shipment of strawberries, pp. 359-366. In: D. G. Richardson and M. Meheriuk (eds.). Controlled atmosphere for perishable agricultural commodities. Oregon State University Symposium Ser. I. Timber Press, Beaverton, OR.

Harvey, J. M., C. M. Couey, C. M. Harris, and F. M. Porter. 1966. Air transport of California strawberries. U. S. Dep. Agric. Market. Res. Rpt. 751. 12pp.

Herner, R. C. 1987. High CO_2 effects on plant organs, pp. 239-253. In: J. Weichman (ed.). Postharvest physiology of vegetables. Marcel Dekker, New York.

Kader, A. A. 1980. Prevention of ripening in fruits by use of controlled atmospheres. Food Technol. 34:51-54.

Kader, A. A. 1985a. Methods of gas mixing, sampling, and analysis. pp. 65-67. In: A. A.Kader, R. F. Kasmire, F. G. Mitchell, M. S. Reid, N. F. Sommer, and J. F. Thompson. (eds.). Postharvest technology of horticultural crops.

Coop. Ext. Serv., University of California, Davis. Special pub. 3311.

Kader, A. A. 1985b. Modified atmospheres and low-pressure systems during transport and storage. pp. 58-64. In: A. A. Kader, R. F. Kasmire, F. G. Mitchell, M. S. Reid, N. F. Sommer, and J. F. Thompson. (eds.). Postharvest technology of horticultural crops. Coop. Ext. Serv., University of California, Davis. Special pub. 3311.

Kidd, F. and C. West. 1922. CO_2 storage of fruit. II. Optimum temperatures and atmospheres. Special Report No. 30. Food Investigation Board, London. pp. 67-77.

Kubo, Y., A. Inaba, and R. Nakamura. 1990. Respiration and C_2H_4 production in various harvested crops held in CO_2-enriched atmospheres. J. Amer. Soc. Hort. Sci. 115:975-978.

Li, C. and A. A. Kader. 1989. Residual effects of controlled atmospheres on postharvest physiology and quality of strawberries. J. Amer. Soc. Hort. Sci. 114:629-634.

Lipton, W. J. 1975. Controlled atmospheres for fresh vegetables and fruits--Why and when, pp. 130-143. In: N. F. Haard and D. K. Salunkhe (eds.). Symposium: postharvest biology and handling of fruits and vegetables. AVI, Westport, CT.

Lougheed, E. C. 1987. Interaction of oxygen, carbon dioxide, temperature, and ethylene that may induce injuries in vegetables. HortScience 22:791-794.

Maas, J. L. 1981. Postharvest diseases of strawberry, pp. 329-353. In: N. F. Childers, (ed.). The strawberry, cultivars to marketing. Horticultural Publications, Gainesville, FL.

Matsumoto, T. T. and N. F. Sommer. 1967. Sensitivity of _Rhizopus stolonifer_ to chilling. Phytopathology 57: 881-884.

Maxie, E. C., F. G. Mitchell, and A. S. Greathead. 1959. Studies on strawberry quality. Calif. Agric. 13(2):11-16.

Metlitskii, L. V., E. G. Salikova, N. L. Volkind, V. I. Bondarev, and V. Y. Yanyuk. 1983. Controlled Atmosphere

Storage of Fruits. Amerinal Publishing Company, Ltd., New Delhi. 150 pp.

Mitchell, F. G. 1985. Postharvest handling systems: temperate fruits. pp. 143-148. In: A. A. Kader, R. F. Kasmire, F. G. Mitchell, M. S. Reid, N. F. Sommer, and J. F. Thompson. (eds.). Postharvest technology of horticultural crops. Coop. Ext. Serv., University of California, Davis. Special pub. 3311.

Mitchell, F. G., E. C. Maxie, and A. S. Greathead. 1964. Handling Strawberries for Fresh Market. Calif. Agr. Exp. St. Circ. 527.

Mohamed, E. S., E. M. El-Zalaki, and T. M. Abu-Bakr. 1986. Effect of cold storage on the quality of Tioga strawberry. Alex. J. Agric. Res. 31(3):171-182.

Morris, L. L. 1969. A two-stage, flow-through system for vegetables, pp. 13-16. In: D. H. Dewey, R. C. Herner, and D. R. Dilley (eds.). Proc. Natl. Controlled Atmos. Res. Conf., Michigan State Univ., East Lasing,MI. Hortic. Rep. 9.

Pantastico, E. B. (ed.) 1975. Postharvest physiology, handling and utilization of tropical and subtropical fruits and vegetables. AVI, Westport, CT. 560 pp.

Rhodes, M. J. C. 1970. The climacteric and ripening of fruits and their products, pp. 521-536. In: A. C. Hulme (ed.). The biochemistry of fruits and their products. Volume I. Academic Press, London.

Ryall, A. L. and W. J. Lipton. 1972. Handling, transportation, and storage of fruits and vegetables. Vol. I. vegetables and melons. AVI, Westport, CT. 240 pp.

Ryall, A. L. and W. J. Lipton. 1979. Handling, transportation and storage of fruits and vegetables. Vol. I. vegetables and melons. AVI, Westport, CT. 588 pp.

Ryall, A. L. and W. T. Pentzer. 1974. Handling, transportation, and storage of fruits and vegetables. Vol. II. fruit and tree nuts. AVI, Westport, CT. 544 pp.

Ryall, A. L. and W. T. Pentzer. 1982. Handling, transportation, and storage of fruits and vegetables. Vol. II. fruit and tree nuts. 2nd Edition. AVI, Westport, CT. 610 pp.

SAS Institute. 1985. SAS User's Guide in Statistics. 5th Edition. SAS Institute, Inc., Cary, NC.

Shaw, G. W. 1969. The effect of controlled atmosphere storage on the quality and shelf life of fresh strawberries with special reference to Botrytis cinera and Rhizopus nigrican. Ph. D. dissertation. 62pp. University of Maryland,College Park, MD.

Sinska, I. and R. J. Gladon. 1985. Ethylene and the removal of embryonal apple dormancy. HortScince 19: 73-75.

Siriphanich, J. 1980. Postharvest deterioration of strawberries as influenced by ethylene and some other volatiles. M.S. Thesis. University of California, Davis. 65 pp.

Smith, W. H. 1957. The application of precooling and carbon dioxide treatment to the marketing of strawberries and raspberries. Scientific Horticulture 12:147-153.

Sommer, N. F. 1985. Principals of disease suppression by handling practices, pp. 75-82. In: A. A. Kader, R. F. Kasmire, F. G. Mitchell, M. S. Reid, N. F. Sommer, and J. F. Thompson. (eds.). Postharvest technology of horticultural crops. Coop. Ext. Serv., University of California, Davis. Special pub. 3311.

Sommer, N. F., R. J. Fortlage, F. G. Mitchell, and E. C. Maxie. 1973. Reduction of postharvest losses of strawberry fruits from gray mold. J. Amer. Soc. Hort. Sci. 98:285-288.

Spayd, S. E., J. R. Morris, W. E. Ballinger, and D. G. Hemelrick. 1990. Maturity standard, harvesting, postharvest handling, and storage, pp. 504-531. In: G. J. Galleta and D. Himlerick (eds.). Small fruit crop management. Prentice Hall, Englewood Cliffs, NJ.

Watt, B. K. and A. L. Merrill. 1975. Composition of foods. U. S. Dep. Agric. Agr. Handb. No. 8. 190 pp.

Wells. 1970. Modified atmosphere, chemical, and heat treatments to control decay of California strawberries. Plant Dis. Rptr. 54:431-434.

Wells, J. M. and M. Uota. 1970. Germination and growth of five fungi in low-oxygen and high-carbon dioxide atmospheres. Phytopathology 60:50-53.

Wills, R. H. H., T. H. Lee, D. Graham, W. B. McGlasson, and E. G. Hall. 1981. Postharvest: An Introduction to the Physiology and Handling of Fruit and Vegetables. AVI: Westport, CT. 161 pp.

Winter, J. D., R. H. Lanon, A. C. Vogele, and W. H. Alderman. 1938. The carbon dioxide treatment of raspberries and strawberries. Proc. Amer. Soc. Hort. Sci. 35: 188-192.

Woodward, J. F. and A. J. Topping. 1972. The influence of controlled atmospheres on the respiration rates and storage behavior of strawberry fruits. J. Hortic. Sci. 46:547-553.

ACKNOWLEDGMENTS

I thank my God, who guided and helped me. I deeply appreciate and thank my co-major professors, Dr. Gail Nonnecke and Dr. Richard Gladon, for their help, guidance, patience, and advice throughout the course of my study. I also express my appreciation to my committee members, Dr. Lester Wilson and Dr. Mark Gleason, for their time and help. Special thanks to Tom Loughin for assistance with statistical analysis and to the staff and graduate students in the horticulture department at Iowa State University, especially Gary Polking, Paul Karlovich, Mehrassa Khademi, Richard Moore, Kim Gaul, and Lori Westrum. Thanks are due to King Saud University of Saudi Arabia for the financial support that made continuation of my graduate studies possible. Thanks are also given to my former English teacher, Anne Richards, and her husband, Iraj Omidvar. I sincerely thank my parents: Nasser and Monirah. May God bless them, as well as my brothers and sisters, for everything they have done for me.

Finally, I deeply thank my wife, Loolwah, for her patience and encouragement during my studies. And my sweet thanks to my two daughters, Affnan and Bayan.

APPENDIX A

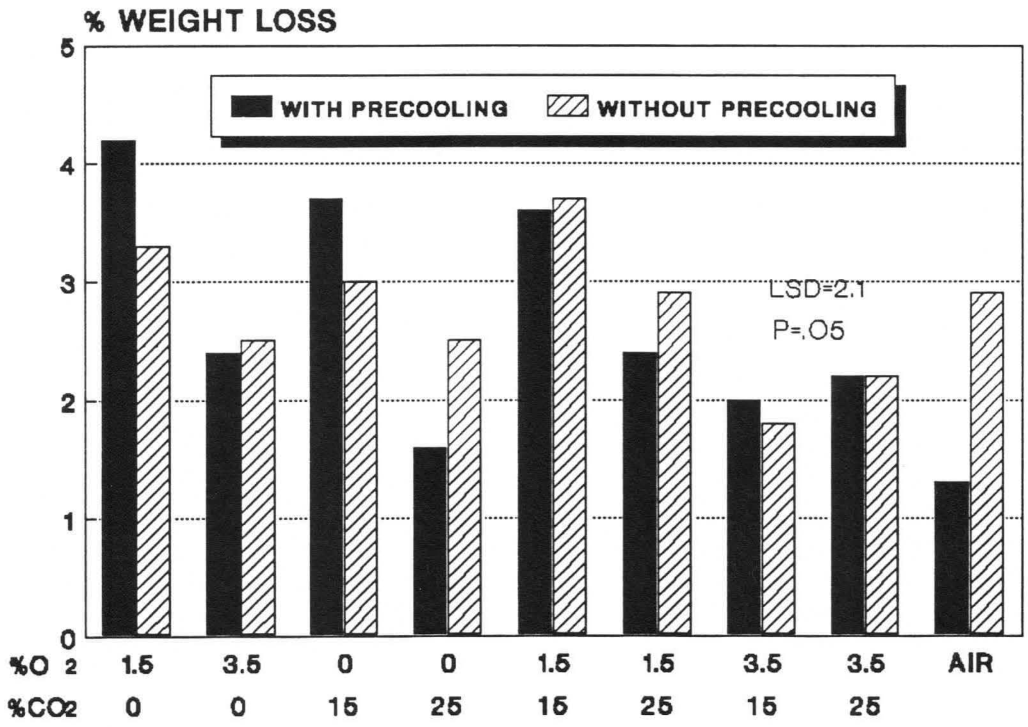

Fig. A1. Influence of modified atmosphere storage treatments on weight loss of precooled and unprecooled 'Honeoye' strawberry after seven days of storage at 2C

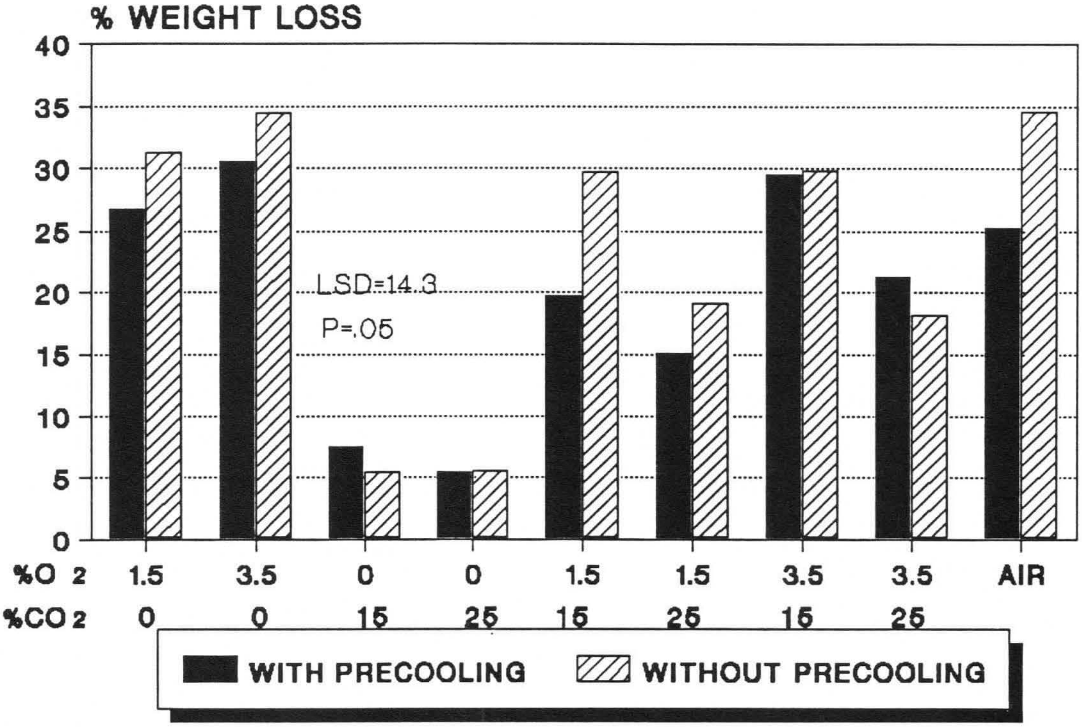

Fig. A2. Influence of modified atmosphere storage treatments on weight loss of precooled and unprecooled 'Honeoye' strawberry after seven days of storage at 21C

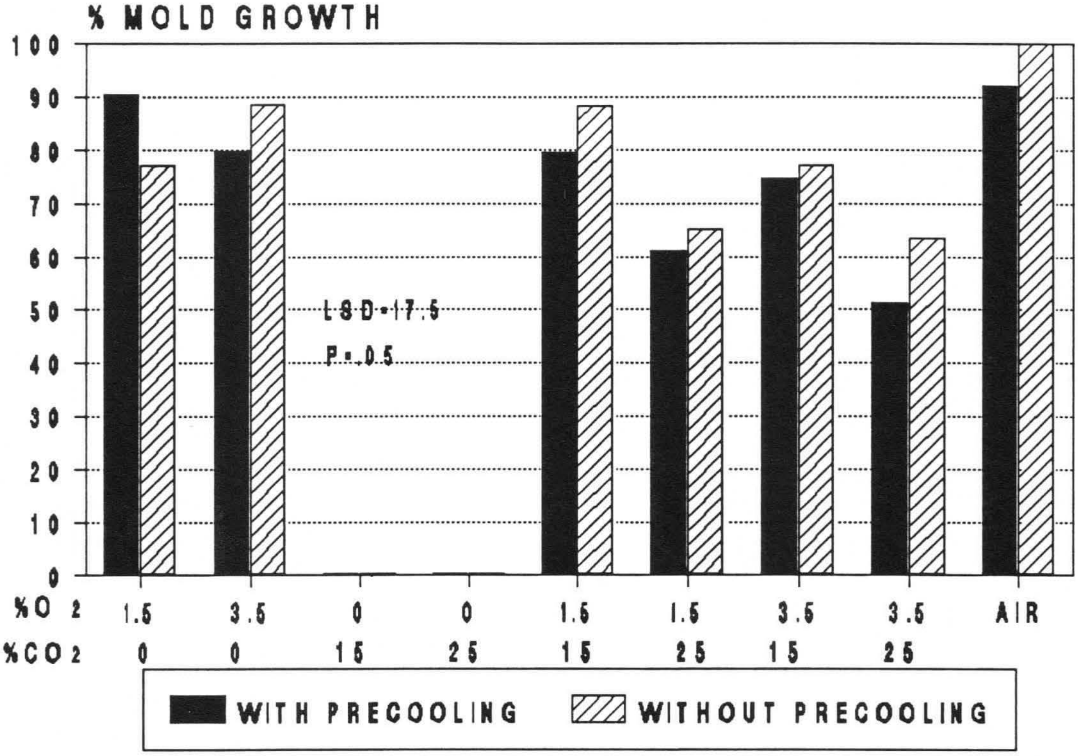

Fig. A3. Influence of modified atmosphere storage treatments on percentage mold growth of precooled and unprecooled 'Honeoye' strawberry after seven days of storage at 21C

Table A1. Influence of modified atmosphere storage treatments and forced-air cooling on weight loss, percentage mold growth, respiration rate, and ethylene production in 'Honeoye' strawberry during seven days of storage at different temperatures[z]

Treatment	weight loss (g)	mold growth (%)	respi- ration rate ($mlCO_2 \cdot kg^{-1}hr^{-1}$)	ethylene produc- tion rate ($\mu lC_2H_4 \cdot kg^{-1} \cdot hr^{-1}$)
MA at 2C				
Cool	7.85	0.0	7.6	0.0
No Cool	8.27	0.0	6.6	0.0
$LSD_{(0.05)}$	2.09	0.0	2.9	0.0
MA at 21C				
Cool	60.99	58.85	28.5	0.054
No Cool	70.23	62.23	29.4	0.063
$LSD_{(0.05)}$	14.30	5.83	2.7	0.030

[z]Each value is the mean of three replications

APPENDIX B

Table B1. Influence of modified atmosphere storage treatments on respiration rate of 'Honeoye' strawberry during seven days of storage at 2C[z]

Treatment		respiration rate ($mlco_2 \cdot kg^{-1} \cdot hr^{-1}$)					
		days in storage					
O_2 (%)	CO_2 (%)	2	3	4	5	6	7
1.5	0.0	5.2	6.2	6.3	7.1	7.1	7.6
3.5	0.0	10.4	9.3	7.9	9.8	9.0	12.0
0.0	15.0	5.1	9.5	7.4	6.5	5.6	6.0
0.0	25.0	9.2	7.2	6.0	5.1	3.0	6.6
1.5	15.0	8.7	6.3	8.8	7.6	7.9	10.5
1.5	25.0	12.9	9.7	11.9	6.9	8.6	8.5
3.5	15.0	9.1	8.2	4.4	4.6	6.2	14.3
3.5	25.0	5.4	7.3	6.8	9.3	8.9	12.0
Air Control		4.3	2.3	3.0	5.2	6.0	8.1
$LSD_{0.05}$		ns[y]	ns	ns	ns	ns	ns

[z] Data were pooled values of cooled and noncooled treatments, and each value is the mean of three replications
[y]ns= no significant difference

Table B2. Influence of modified atmosphere storage treatments on respiration rate of 'Tristar' strawberry during seven days of storage at 2C[z]

Treatments		respiration rate (mlCO_2 $kg^{-1} \cdot hr^{-1}$)					
		days in storage					
O_2 (%)	CO_2 (%)	2	3	4	5	6	7
1.5	0.0	8.8	7.6	6.36	6.3	8.1	8.55
3.5	0.0	6.65	5.7	7.9	6.2	6.36	5.2
0.0	15.0	5.9	6.65	8.3	5.2	5.9	6.2
0.0	25.0	7.1	5.9	6.36	3.04	1.9	2.4
1.5	15.0	7.6	2.56	8.7	6.9	9.2	2.37
1.5	25.0	0.0	0.5	5.7	2.37	6.17	7.1
3.5	15.0	5.4	5.2	4.3	10.45	6.8	7.1
3.5	25.0	3.8	6.2	6.4	8.7	16.2	14.3
Air Control		7.8	5.8	6.8	7.3	5.5	5.9
$LSD_{0.05}$		ns[y]	ns	ns	ns	ns	ns

[z]Each value is the mean of four replications
[y]ns= no significant difference